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TECHNOLOGIC PAPERS

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BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 91

TEMPERATURE MEASUREMENTS IN BESSEMER AND OPEN-HEARTH PRACTICE

BY

GEORGE K. BURGESS, Physicist.

Bureau of Standards

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George K. Burgess

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I. INTRODUCTION

The suggestion has often been made that it would be highly desirable, at least for certain grades of steel and perhaps for all, to be able to control more certainly, by pyrometric measurement or otherwise, the temperatures of the operation of the open-hearth and other furnaces used in the manufacture of steel and iron. At present in the usual open-hearth practice, for example, dependence has to be placed on the melter, who may acquire a considerable degree of skill in balancing the incipient melting of furnace roof and walls against the heat supply. He is guided also by other appearances within the furnace and is aided, of course, by his cobalt-blue glass. The behavior of the metal in the test mold and in the sampling spoon gives him a further indication of the temperature, as does also the appearance of his iron-stirring pole.

That the properties of the ingot and finally of the finished steel product are intimately related to the final temperatures attained by the metal in the furnace and to the temperature of casting has been recognized by metallurgists for a long time, and this question has been very thoroughly treated, especially by Prof.

Howe. It is of interest to note in a recent study of the properties of ingots by A. W. and H. Brearley,[1] in which many of the factors dependent upon casting temperatures are emphasized, that the regret is expressed that "there is no handy means whereby the casting temperatures of steel can be accurately measured." In casting to size, as chilled iron wheels, for example, the rôle of temperature is, if possible, even more important than in casting ingots, as most of the defects introduced by too high or low temperatures have no possibility of subsequent removal.

It is the object of this paper to demonstrate that in so far as casting temperatures of furnaces, steel ingots, and similar operations involving the temperatures of streams of iron and steel are concerned, well-known pyrometric methods may easily be applied with a relatively high degree of accuracy if certain recently determined corrections are made and precautions taken. Greater but not insurmountable difficulties will be encountered in the case of open-hearth furnace temperatures, while for those of the converter type a ready solution does not seem practicable.

Attempts have been made, beginning, we believe, with the pioneer observations of Le Chatelier in 1892, to estimate with some degree of accuracy the order of magnitude of the temperatures involved in some of the physically more inaccessible operations of steel manufacture. A few other such observations, usually related to some particular problem and not generally to the question of temperature control, have been published. Nevertheless, it appears, certain essential data have always been lacking in reporting these observations. Thus, the correction to be applied for the characteristic radiation, or emissivity, has hitherto not been adequately taken into account nor the limitations of the several possible pyrometric methods clearly recognized, as, for example, when the apparent temperature of flames issuing from the Bessemer converter has been assumed to be a measure of the metal temperature.

In ordinary open-hearth practice—limiting ourselves to liquid steel—there are at least three operations the temperatures of which it may presumably be of interest to determine, namely, (1) of the furnace itself or of its charge at any time preceding its tapping, (2) of the stream of metal and slag being tapped from furnace into ladle, and (3) teeming from ladle into ingot or other molds.

Let us consider the possibilities of each of these. In view of the fact that the temperature to be measured in all of these operations

[1] A. W. and H. Brearley, Some Properties of Ingots, Iron and Steel, Institute of Great Britain; September, 1916.

is usually above 1500° C (or 2700° F) and may reach to above 1750° C (or 3200° F), it is manifestly advantageous to use methods of measurement in which there is no contact with the heated metal or slag; this is also desirable for evident mechanical reasons. We are limited, therefore, to the optical and radiation types of pyrometer. Preference will be given to the former for the reason that the errors in the use of the radiation pyrometer caused by intervening gases, distance, size, and specific radiation (emissivity) of objects sighted upon are greater and more uncertain than with the several forms of optical pyrometer [2] using monochromatic light.

II. FURNACE TEMPERATURES

Although one may arrange to observe temperatures of any portion of the open-hearth furnace and also of the slag surface, what one is mainly interested in is the temperature of the metal, and this appears to bear but a remote relation to that of the roof and walls, on which the heat of the fuel impinges. There are, apparently three temperature zones, viz (1) the dome of the furnace, (2) the slag, and (3) the metal. The first of these may vary quite rapidly with changes of fuel supply, opening doors, etc., and locally with reversal of firing. The slag temperature changes less suddenly and in amount, and that of the metal least, with variations in furnace operations.

Pyrometric control of temperatures of the roof is easy and may be exact and, although somewhat misleading, may also be made without serious interference from gases and smoke by sighting through suitably placed ports, and should be useful primarily in preventing overheating, which, of course, shortens the life of the furnace by melting the bricks. The temperature of the arch is oftentimes kept very close to the melting point of the bricks, which may become locally overheated and begin to "drip." With a knowledge of their melting range this wasting away of the bricks by overheating may be retarded by pyrometric control. Observation of temperatures within the furnace is simpler than of streams of metal or slag in that no correction of any importance has to be applied to the optical-pyrometer readings for selective radiation. (See Sec. VI.)

It might be possible to arrange in the furnace or metal bath a closed-end tube of refractory material into which either an optical

[2] Burgess and Foote, Characteristics of Radiation Pyrometers, Bureau of Standards Bull. 12, p. 91, 1915; Waidner and Burgess, Optical Pyrometry, Bureau of Standards Bull. 1, p. 189, 1904.

or radiating pyrometer might be sighted, thus obviating gases, etc. This presents very considerable mechanical difficulties and, although used in ceramic furnaces, does not appear to have been successfully accomplished for furnaces melting steel.

The temperature conditions in the bath of the open-hearth furnace may be, perhaps, most easily determined by sighting an optical pyrometer through a peephole in a door or through a port upon the surface of slag, preferably near the center of the bath. This temperature is not usually that of the metal but does not, in general, appear to be far removed from the metal temperature, especially as the time of tapping the furnace approaches and the fuel supply has been fairly regular and uniform.

The temperature of the metal itself may be determined, but not as readily and surely as one could wish, by removing with a preheated spoon some 50 pounds and sighting upon the surface of this metal contained in the spoon with an optical pyrometer, taking a series of temperature-time readings and noting exactly the instant of withdrawal of metal and of temperature readings, from which data the temperature of the metal in the furnace may be estimated. Here not a few complications arise, such as the slag residue and the formation of oxides on the surface, their solidification sometimes before the steel and other surface effects dependent upon the condition of the steel, escape of gases, etc., with attendant uncertainties in temperature readings, the speed required in taking readings and other difficulties of rapid manipulation and operations, for which at least three persons are required, whereas one observer is sufficient in taking temperatures of furnace and slag.

Illustrations of all these methods of estimating temperatures of furnace, metal, slag, and stream are given in Section VII.

There appears to be, as yet, no pyrometric method which has been adapted to give satisfactorily the temperature of the metal in the Bessemer converter. The apparent temperature of the flames may be, of course, observed, but this has yet to be shown to bear any definite relation to the metal temperature. There are, fortunately, other methods of recognizing the status of the reactions and the moment when a Bessemer heat is ready to cast.

III. FURNACE-TAPPING TEMPERATURES

If one can get a side view and within 50 feet of the smoke-free side of the tapping stream of an open-hearth or Bessemer furnace, accurate observations may easily be taken of its temperature.

Even under less favorable conditions, as when sighting upon the stream from a distance, good observations may be obtained. The pyrometer here, however, no longer gives true temperatures directly; the observed temperatures must be corrected for the emissivity or specific radiation of the metal or slag, a correction depending on the radiation which is characteristic of the stream surface and upon the color of the light used in the pyrometer. (See Section VI.)

The greater brightness of the slag, readily noticed with the unaided eye, is caused by its higher emissivity and also in part sometimes by the fact that it may be slightly hotter than the metal. Slag, however, is not a material of uniform composition, nor is its brightness always the same from one cast to another at the same temperature. It follows that pyrometric estimations of slag-stream temperatures may be attended with considerable uncertainty.

IV. TEEMING TEMPERATURES

Here we have almost ideal conditions for obtaining accurately the temperature of the stream, which is clean metal with a slight evanescent surface of oxide, giving to the stream, viewed through red glass, a characteristic transparent appearnace, the color of the metal being greenish and of the oxide yellow. The corrections to be applied to the temperatures for the emissivity of iron viewed in red light have been exactly determined.[3]

V. LIMITATIONS AS TO PYROMETER STATION

The arrangement of the open-hearth or Bessemer mills is a considerable factor as to convenience with which temperature observations of furnace, tapping, and teeming may be taken. Thus, for one set of open-hearth furnaces the location and accessibility of the ports may be such that the bath of the metal and slag can each be sighted upon; for another set only parts of the roof and walls can be observed conveniently. Again, the tapping stream is sometimes accessible and sometimes it is necessary to view the stream from a distant gallery. The same is also true of observations of teeming temperatures. Usually it is possible, however, to bring the pyrometer to within 10 feet of the stream when teeming ingots, but distant observations, even to 100 feet or more, may be taken with but a slight increase in uncertainty.

[3] The Emissivity of Metals and Oxides: II. Measurements with the Micropyrometer, G. K. Burgess and R. G. Waltenberg, Bureau of Standards, Bull. 11, p. 591; 1915.

These difficulties of pyrometer stations, however, usually can be readily overcome. It is evidently necessary to have a portable apparatus that may be moved about while taking observations and one that may be sighted from a considerable distance on a stream issuing from a 2 or 3 inch nozzle.

VI. PYROMETRIC METHOD AND EMISSIVITY CORRECTIONS

The observations described below were taken with the Holborn-Kurlbaum form of Morse pyrometer, which has been frequently described,[4] although, of course, other types of optical pyrometer might have been used. The outfit is portable and readily adjusted and permits taking temperature readings as fast as they can be recorded. The instrument is calibrated so as to give correct temperatures when sighting into a clear, closed furnace at uniform temperature, which approaches the theoretical condition of a "black body," which is said to have an emissivity equal to unity.

When sighted on an incandescent, free surface having a specific radiation or emissivity e, always less than 1, its true temperature centigrade t $(=T-273)$ may be computed from its apparent (too low) temperature s $(=S-273)$ by means of the formula

$$\log_{10} e = \frac{c \log E}{\lambda}\left(\frac{1}{T}-\frac{1}{S}\right)$$

where $c=14\,500$, E the Naperian base, and λ the wave length of light used in the optical pyrometer; here $\lambda=0.65\ \mu$. This type of formula holds for any optical pyrometer using monochromatic light. The accuracy attainable in practice by this method is about 5° C. at 1500° C.

The emissivity (e) of a smooth surface of liquid iron free from oxide is 0.37 (for $\lambda=0.65\mu$), and no appreciable difference appears to exist between the emissivities of pure iron and of the steels containing considerable percentages of carbon, nickel, or manganese, nor is there any appreciable variation of emissivity with temperature.[5] A solid surface of incandescent iron, which has the same emissivity as the liquid, can not be maintained free of oxide in practice; it is always the oxide which is observed. Liquid iron oxide has a somewhat higher emissivity, 0.53, than liquid iron and a very much less value than the solid oxide, the emis-

[4] Bureau of Standards, Bull., 1, p. 139, 1904; and Technologic Paper No. 38; Measurement of High Temperatures, 1912 ed., Burgess and LeChatelier.

[5] See note 3, p. 7.

sivity of which is about 0.92. Liquid slag has a variable emissivity of uncertain limits, depending on composition, but probably usually ranging between 0.55 and 0.75, and 0.65 is apparently the usual value of e for "dark" slag. For reasons noted in Section IV the emissivity of the metal stream of steel is taken as 0.40 instead of 0.37 in computing true temperatures in the following Section VII.

In the accompanying Table 1 are given the corrections to be added to readings of optical pyrometers using red light of wave length $\lambda = 0.65\mu$ for a series of values of emissivity. The observed temperatures are expressed in ordinary centigrade degrees.

TABLE 1

Corrections to Add to Temperature Readings for Emissivity

Emissivity	Pyrometer using red light, wave length $\lambda=0.65\mu$, at observed temperatures, degrees centigrade of—										
	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	2000
0.30	80	94	110	127	146	166	188	211	235	262	318
0.40	59	70	82	95	108	123	139	156	174	193	234
0.50	44	53	62	71	81	92	104	116	129	143	173
0.60	32	38	45	51	59	67	75	84	93	103	124
0.65	27	32	37	43	49	56	63	70	78	86	104
0.70	22	26	31	36	41	46	52	58	64	71	86
0.80	14	16	19	22	25	28	32	36	40	44	53
0.90	7	8	9	10	12	14	15	17	19	21	25

As reference temperatures it may be useful to recall that pure iron melts at 1530° C.[6] (2786° F.), so that, using the above pyrometric method, pure iron just melting would have an apparent temperature of 1405° C (2561° F). Similarly, a liquid stream of steel at a temperature just above its melting point, or at 1475° C (2687° F), will appear to be at 1358° C (2476° F). If the liquid oxide surface of iron or steel, however, is viewed at 1530° C, it will have an apparent temperature of 1440° C (2624° F), while solid steel or iron (always the oxide) will have an apparent surface temperature, as viewed with an optical pyrometer, practically equal to its true for any temperature whatever.

VII. OBSERVATIONS

In the following tables are given certain typical series of observations (taken from among many obtained in several large steel

[6] Burgess and Waltenberg, Bureau of Standards, Bull., 10, p. 79; 1914.

plants the past few years) of furnace and stream temperatures, including all the cases mentioned above. The attempt has not been made here to correlate the ingot or heat characteristics with the temperature, although some data have been accumulated on this subject. It is believed, however, that these observations demonstrate the possibility of obtaining accurate temperature observations for the establishment of any of the numerous correlations which may be suspected to exist, and it is also believed that these observations indicate the practicability of pyrometric control of open-hearth practice, ingot casting, and similar operations. Of course the tracing out of the effect, say, of casting temperatures upon this or that ingot characteristic presupposes the possibility of varying mill practice at will; and in any particular case, considering the large number of other variables that may enter, it will probably take a carefully laid out plan involving a considerable quantity of metal (some of which will undoubtedly be scrapped) to accomplish the end sought. This is also a case where the experimental work has to be done on the same scale as in practice.

1. OBSERVATIONS IN BESSEMER MILL

In Table 2 is given the record of furnace casting and ingot teeming temperatures for 19 consecutive Bessemer heats of some 20 tons each of rail steel with a statement of the condition of the ladle as observed by the melter. The temperature estimation of the stream pouring from the converter may be rendered somewhat uncertain by the interference from smoke during the addition of spiegel, to the intermittent presence of slag, and to the considerable distance from which the stream was viewed, since the pyrometer was located on an opposite gallery adjacent to the ingot molds. The temperatures given in the table for pouring the converter are each based on a series of observations taken after the addition of spiegel. It is assumed somewhat arbitrarily that the emissivity of this stream is 0.45, corresponding to a temperature correction of 119° C, which gives an average converter-pouring temperature of 1595° C (2903° F). This may be somewhat low. If these apparent temperatures were for a more strictly metallic stream ($e=0.40$), the true pouring temperature would be 1623° C (2953° F), on the average.

We may speak with considerably greater exactness concerning the teeming temperatures. In the table each temperature recorded is the average of several observations, usually three or four, taken

during the filling of an ingot mold of 3½ tons capacity, this operation occupying a time somewhat less than a minute. The emissivity of this stream is taken to be 0.40, which is probably exact to within 0.02, corresponding to a precision of 10° C at 1500° C. The corresponding correction to observed temperatures is about 125° C. In the table are also given the observed temperatures uncorrected for emissivity; the average temperatures only are corrected.

From the horizontal lines of this table an idea is obtained of the precision of the pyrometric measurements, while the vertical lines show the uniformity of practice in pouring heats. The most striking facts these observations bring out are the relatively narrow temperature range of less than 50° C within which the Bessemer converter may be and apparently must be operated and the corresponding remarkable uniformity of ingot-teeming temperatures.

It will be noted that the temperature drops on the average some 50° C or more while in the (preheated) 20-ton ladle, and the sixth ingot is teemed at about 25° C lower temperature than the first.

It was deemed impracticable to attempt to measure the temperature of the charge in the converter, and it was not considered that the apparent temperature of the flames would bear any definite relation to the unknown and rapidly changing temperature of the metal. A few observations of apparent flame temperatures and also of the converter interior were taken, but they were quite erratic.[7]

2. OBSERVATIONS IN OPEN-HEARTH MILLS

(*a*) *Temperature of Metal and Slag Streams.*—In Table 3 are shown the casting and teeming temperatures for a series of heats and top-poured ingots of rail steel from a bank of 60-ton basic open-hearth, tilting furnaces. As some four to six minutes are taken in tapping such an open-hearth furnace bath the slag and metal streams may be observed, although it is necessary, on account of the pyrometer station being for this series on opposite gallery, to wait for the smoke to clear away after additions are made to the metal in the ladle. The emissivity of the metal is taken as 0.40, and, if that of the (dark) slag is assumed to be 0.65, the slag and metal streams have on the average the same temperature of 1607° C. There is here seen to be, as in the case of the

[7] Wüst and Laval in an important study of the converter process (Metallurgie, 5, pp. 431, 471, 1908) give a series of converter flame temperatures for a single charge which they find to increase from 1040 to 1500° C during a blow, and they estimate the metal to be some 50° hotter than indicated by the apparent flame temperatures.

Bessemer converter (Table 2), a very inconsiderable variation in temperature from one heat to another. The metal had its temperature lowered in the ladle by about 55° C before teeming, and the nineteenth ingot was cast on the average at some 35° C lower temperature than the first. The casting temperatures of the open-hearth and Bessemer practice here shown are seen to differ but slightly.

In Table 4 are given the tapping and teeming temperatures for a series of heats of steel of various compositions from acid and basic open-hearth furnaces in another steel plant, together with certain heat characteristics as noted by the melter. There will be remarked the uncertainty of slag stream temperatures associated principally with the varying color of the slag; and, further, that all these heats were satisfactory and the heat of the metal in each case was rated as "hot," which here is seen to correspond to a tapping temperature above 1600° C and a teeming temperature between 1550 and 1600° C, whereas the teeming temperature of the Bessemer and open-hearth rail ingots of Tables 2 and 3 ranged very closely about 1525 and 1550° C, respectively.

In Table 5 are shown the very satisfactory detailed observations of the temperatures of tapping of several open-hearth furnaces, the estimates of the temperatures of which are contained in Tables 4 and 9. The observations of Table 5 were taken by viewing the stream from the side with the pyrometer within 20 feet of the tapping stream. It will be noted from Table 5 that the heat may or may not be distributed uniformly through the metal in the furnace, but the uniformity attained would seem to depend, in part at least, on the melter. Thus, the temperature of the stream of heat 7–14 falls off some 80° C in the two minutes of pouring; that of heats 8–79 and 10–90 remains reasonably constant; and the temperature of the stream of heat 12 × 36 increases some 50° C, showing that the top of the bath must have been considerably hotter than the bottom. The extreme range here observed in the temperature of metal in tapping stream is 1710 to 1520° C.

In order to show how readily and accurately the temperature of a stream from a furnace which is being tapped may be followed the actual readings taken for tapping heat 12 × 36 are given in Table 6 and Fig. 1. The conditions of observing this tapping stream were less favorable, due to smoke, than was usually had. The fluctuations in pyrometer readings, particularly at start and finish, are partly caused by intervening smoke. A piece of slag will give an occasional high reading. It will be seen that observations with

the optical pyrometer may be taken easily at the rate of six or eight a minute. The observations on tapping another heat 13×85 are also shown in Fig. 1.

The temperatures of miscellaneous operations involving metal streams are given in Table 7. The average values in each case have been corrected for emissivity on the basis that $e = 0.40$. All observations were taken with the Morse optical pyrometer.

(*b*) *Open-Hearth Furnace Temperatures.*—Observations of temperatures of open-hearth furnaces are given in Table 8 for some of the same heats as the casting temperatures of Table 3. The readings of the Morse and Féry pyrometers are corrected for instrument errors, but no correction has been applied for emissivity or for absorption of radiation by the gases within the furnace. In the case of the Féry pyrometer, based on total radiation and calibrated in terms of the Stefan-Boltzmann law,[8] the correction will be much larger than for the Morse or other optical pyrometer. As the amount of gases in the various parts of the furnace vary from time to time, it is not practicable to make any correction for the absorption of these gases. The use of a total-radiation pyrometer to determine furnace temperatures does not appear to be warranted.

Each furnace had three doors with openings through which the slag bath could be observed. The method of firing here used deflected the flames down on the bath surface, so that the flames interfered quite seriously with obtaining satisfactory observations. The effect of intervening flames is usually to cause the pyrometer to read too high temperatures. Those taken with the optical pyrometer through the middle door are, however, fairly satisfactory. The furnace-casting temperature and that of teeming of first ingot is added for comparison.

An indication of the uniformity of heating the open-hearth bath is seen by comparing the slag and metal casting temperatures with that of the slag surface as viewed in the furnace. Thus, for heat 3×98 the slag in the furnace has attained the unusually high temperature of 1700° C, and maintained this for 20 minutes up to 10 minutes before tapping. The slag stream is seen to be at 1621° and the metal at only 1559°. The slag stream appears to be usually slightly hotter than the metal and the relation of the two is undoubtedly dependent upon the details of methods of firing. In noting the considerable difference between furnace and slag stream temperatures it is also to be remembered that the

[8] Burgess and Foote, Bureau of Standards Bull., 12, p. 91; 1916.

furnace cools very rapidly when heat is shut off, which often occurs several minutes before tapping.

In Table 9 are given some further measurements of temperatures of open-hearth acid and basic furnaces for the heats of Table 4, the most complete being those of acid-furnace heat 12×36, which was followed in detail for four and one-half hours before tapping.

Three methods of observation were used, namely, sighting through small ports situated well to right or left corners of furnace, the pyrometer being directed toward middle back wall of furnace at arch and wall intersection; on the surface of 30 to 50 pounds of metal removed from furnace in a spoon; and on the slag in middle of the bath through peephole in center door.

That the roof temperatures may have no relation to those of the metal is again seen from the observations of heat 10×90, for which the fuel was cut off for 20 minutes immediately preceding casting and the temperature of the arch fell from 1700 to 1378° during the first 14 minutes, while the metal on the average remained above 1585°, although the observations on the metal spooned out show the metal at the top of the bath was cooling very rapidly from 1640 to 1520° during those 20 minutes of no heat being applied.

The temperatures of the arch are seen to be higher generally than the bath or metal temperatures, usually by some 50° C, although there appears to be no definite relation, except that when the furnace has been clear for some time (see Table 9) the bath and arch temperatures tend to become equal.

All of these heats were rated as "hot" by the melter, and the behavior of the metal in the molds was good.

The metal temperatures taken by observing the metal in a spoon, as shown in Table 9, are not as satisfactory as one could wish. They are not, however, inconsistent with the casting temperatures and those of the bath when sighting on the slag surface. There is some uncertainty as to the best value of emissivity to use for the clear surface (always greenish in color) of the liquid metal in the spoon. The value here taken is $e=0.40$, but there soon develops a haze over the surface, probably of oxide, although a pronounced oxide surface, for which $e=0.53$ will not usually form on a well-skimmed, hot surface until the temperature has fallen considerably. It appears as if the oxide first formed by the air in contact with the very hot liquid metal is dissolved. It is possible that a value of $e=0.45$ for the emissivity of this surface would be more exact. The recorded "spoon" temperatures would then have to be lowered by some 15 or 20° C.

The procedure followed for securing temperature determinations of the metal bath by means of observations on the surface of the metal dipped out in a spoon was as follows:

A place was marked on the floor near the open-hearth furnace charging door and the optical pyrometer sighted upon this mark at an angle of about 45° and set to the approximate reading expected; a spoon to hold 30 to 50 pounds of metal was first preheated, then filled with metal and placed on the mark; the metal was skimmed of slag with a single sweep of wood, and the taking of temperature observations begun immediately. The instant of removal of spoon from the furnace and of each temperature observation was noted with a stop watch; also the condition of the surface was observed, whether clear, hazy, oxide, slag, liquid, or solid, quiet or boiling, or scintillating. Skimming the surface more than once had sometimes to be resorted to if the steel was not quiet, but with quiet metal the best results were obtained by leaving the surface intact after the first skimming and noting the formation of oxide and applying the emissivity correction for metal or oxide. Temperature observations can usually be begun within 12 seconds of removal of spoon from furnace.

The last two determinations in the spoon of metal temperature of heat 12×36 (Table 9) are shown graphically in Fig. 1.

A comparison of the temperatures of several open-hearth furnaces for a time of three hours in various stages of melting is given in Table 10, the observations being taken by sighting on the surface of the slag. There appears to be no very considerable differences for the five furnaces after melting has taken place, whatever the condition of the metal; the temperatures ranged from 1567 to 1679° C and were usually above 1620° C. The bath temperatures (compare also Tables 8 and 9), when they can be taken under conditions in which the flames from the fuel do not interfere, as in Table 8, appear to give a fairly good indication of the temperature of the upper surface layer of the metal. If the stirring or heating has not been well done, however, the observations will be misleading if they are taken to apply to the metal as a whole.

VIII. SUMMARY AND CONCLUSIONS

The problem of temperature measurement and pyrometric control of furnace casting and ingot teeming temperatures is shown, by a series of observations taken in several steel plants, to present no serious difficulties or uncertainties.

For this purpose the most satisfactory type of instrument is one of the optical pyrometers using monochromatic light and permitting observation from a distance of streams of metal.

It is shown that the necessary corrections to the observed optical pyrometer readings for emissivity of metal and oxides to give true temperatures are sufficiently well known, but there may be uncertainty in the case of liquid slags.

For streams of liquid iron or steel the most probable value of emissivity to take, with a pyrometer using red light of wave length $\lambda = 0.65\ \mu$, is $e = 0.40$, corresponding to a correction of 139° for an observed temperature of 1500° C. The value of e for liquid slags is usually about 0.65 but varies with composition of the slag. A table of emissivity corrections is included in the text. (See Table 1.)

Determination of the temperature of the charge of Bessemer converters is not deemed practicable by pyrometric methods.

The operation of the open-hearth furnace can be gauged by the pyrometer, it being possible to control readily the temperature of the roof and of the bath of metal and slag by observations taken through ports, and the temperature of the metal may be had at any instant, with a fair degree of exactness, by observation with the optical pyrometer of the surface of 50 pounds of metal removed in a spoon. This operation is more certain with acid than with basic practice, the basic slag being more difficult to remove.

The temperatures of the roof of an open-hearth furnace are shown to bear no necessary relation to that of the metal bath, which again is shown may have zones of considerable differences in temperature, depending upon the operation of the furnace.

The temperature of the roof of an open-hearth furnace, dependent upon the firing practice, may vary very rapidly and within wide limits, 1550 to 1750° C. The temperature of the open-hearth bath is usually kept between 1600 and 1670° C.

There appears to be a remarkable degree of uniformity in casting temperatures actually acquired by the melters in practice. Thus, for 19 consecutive Bessemer heats the teeming temperatures of the ingots were all between 1500 and 1555° C., and a similar degree of concordance, although at slightly higher temperatures, was found in the open-hearth practice of several mills.

It is believed that a continuous, systematic following of the temperature by the methods above outlined for the various furnace and casting practices on the part of steel and iron mills

would show the possibility of improvements and greater certainty of production in quality of product; also changes and the effects of variation in ingot or furnace practice could undoubtedly be carried out with greater certainty than at present appears to be the case.

Several observers assisted in taking the above observations, and acknowledgment of such assistance is due to Messrs. Crowe, Merica, and Waltenberg, of the metallurgical division of the Bureau of Standards.

Acknowledgment of the opportunity of taking these observations is also gladly made to the management and members of the technical staff of the steel plants at Sparrows Point, Md., Philadelphia and Bethlehem, Pa., and Washington, D. C.

WASHINGTON, November 7, 1916.

OBSERVATION TABLES

TABLE 2

Temperature Observations in Bessemer Mill[a]

Heat No.	Apparent temperature of metal pouring from converter	Apparent temperature of pouring into ingot molds—						Mean of 1–6	Average true temperature of 1–6	Ladle
		1	2	3	4	5	6			
29	1476	1397	1377	1377	1389	1369	1367	1379	1500	Spots.
30	1472	1401	1387	1393	1401	1397	1393	1395	1517	Do.
31	1488	1415	1419	1403	1393	1383	1375	1398	1521	Do.
32	1458	1397	1389	1387	1379	1387	1387	1388	1510	Spots; clean.
33	1468	1407	1401	1407	1405	1403	.....	1405	1529	Spots.
34	1454	1417	1405	1431	1391	1389	1413	1408	1532	Clean.
35	1462	1419	1417	1403	1393	1405	.....	1407	1531	Do.
36	1490	1434	1429	1432	1429	1419	1417	1428	1555	Do.
37	.....	.....	.....	.....	1383	1372	1397	1384	1505	Skull, 4000-pound.
38	1490	1385	1393	1377	1403	1385	1385	1388	1510	Cut 1500-pound skull.
39	1478	1429	1403	1393	1389	1379	1377	1398	1521	Do.
40	1486	1424	1408	1408	1401	1399	1399	1406	1530	Spots; cut 1000-pound skull.
41	1492	1436	1401	1375	1389	1424	1399	1404	1528	Clean.
42	1468	1408	1403	1408	1397	1391	1379	1398	1521	Clean; spots.
43	.....	1434	1419	1409	1407	1389	1372	1405	1529	Hot.
44	1488	1433	1419	1409	1405	1391	1383	1407	1531	Do.
45	1474	1405	1405	1405	1403	1401	1387	1401	1524	Spots No. 1.
46	1462	1383	1383	1383	1391	1383	1403	1387	1509	Spots.
47	1484	1434	1432	1417	1413	1413	1409	1419	1545	Warmer; clean ladle.
Mean	1476	1414	1405	1401	1398	1394	1391	1400	1523	
Emissivity correction	119	126	124	123	123	122	122	.....	.....	
Mean true temperature, °C.	1595	1540	1529	1524	1521	1516	1513	.....	1523	

[a] ϵ=0.45 for converter metal; ϵ 0.45 for ingot teeming.

TABLE 3

Temperatures of Casting Open-Hearth Furnaces and Ingots [a]

Furnace and heat numbers	Apparent temperature of pouring into ladle		Apparent temperature of pouring into ingot molds—															
	Metal	Slag	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Furnace 5; heat 64	1490	1540	1415	1403	1419	1413	1413	1407	1407	1413	1405	1399	1403	1403	1397	1393	1401	1397
Furnace 3; heat 97	1464	1546	1409	1385	1379	1380	1367	1385	1385	1393	1389	1393	1389	1387	1389	1415	1399	1401
Furnace 5; heat 65	.....	1545	1391	1407	1413	1417	.....	1417	1419	1413	1405	1409	1409	1393	1375	1383	1389	1401
Furnace 3; heat 98	1431	1554	1405	1417	1421	1417	1417	1415	1409	1409	1407	1407	1406	1407	1417	1417	1403	1403
Furnace 4; heat 62	1508	1571	1407	1399	1413	1387	1387	1389	1387	1383	1383	1385	1383	1381	1387	1383	1387	1365
Furnace 1; heat 32	.....	.....	.....	.....	1466	1457	1434	.....	1448	1429	1427	1427	1419	1427	1417	1421	1409	1413
Furnace 1; heat 25	.....	1530	1448	1403	1397	1403	1408	1393	.....	.....	1429	1401	1389	1397	1397	1417	1410	1415
Furnace 2; heat 10	1499	.....	1427	1415	1415	1408	1410	1398	1401	1412	1417	.....	1397	1401	1397	1403	1397	1392
Furnace 3; heat 73	1425	1520	1427	1427	1410	1398	1397	1410	1412	1415	1415	1412	1410	1408	1406	1422	1401	1397
Furnace 3; heat 74	1429	1572	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Furnace 4; heat 51	1490	1546	1415	1429	1420	1417	1420	1415	1412	1410	1417	1415	1415	1403	1406	1412	1415	1410
Furnace 1; heat 36	.....	1525	1439	1439	1427	1420	1424	1427	1417	1410	1412	1410	1408	1415	1410	1412	1420	1410
Furnace 1; heat 41	.....	1527	1448	1457	1457	1450	1448	.....	1439	1446	1441	1443	1439	1439	1420	1427	1420	1427
Furnace 3; heat 80	1478	1546	1450	1415	1420	1427	1420	1422	1429	1406	1408	1406	1422	1415	1410	1417	1420	1408
Furnace 1; heat 42	1516	1545	1441	1438	1434	1438	1438	1422	1448	.....	1422	1424	1417	1408	1410	1410	1415	1398
Furnace 3; heat 82	.....	1532	1424	1406	1408	1406	1401	1401	1412	1401	1397	1398	1403	1408	1406	1397	1392	1394
Furnace 1; heat 43	1468	1532	1415	1406	1394	1410	1401	1392	1397	.....	1397	1397	1392	1375	1397	1385	1380	1387
Mean	1473	1542	1424	1416	1418	1416	1412	1407	1415	1411	1411	1408	1406	1404	1403	1407	1404	1401
Emissivity correction	134	66	127	125	125	125	125	124	125	125	125	124	124	123	123	124	123	123
True temperature	1607	1608	1551	1541	1543	1541	1537	1531	1540	1536	1536	1532	1530	1527	1523	1531	1527	1524

[a] e=0.40 for metal streams; e=0.65 for slag.

TABLE 3—Continued

Temperatures of Casting Open-Hearth Furnaces and Ingots—Continued

Furnace and heat numbers	Apparent temperature of pouring into ingot molds—										Apparent temperature, average	True temperature, average	Remarks
	17	18	19	20	21	22	23	24	25	26			
Furnace 5; heat 64											1405	1529	Spots.
Furnace 3; heat 97											1390	1512	8000-pound skull. Melter during teeming said this heat poured hot.
Furnace 5; heat 65	1391										1402	1525	500-pound skull.
Furnace 3; heat 98	1405	1403	1417								1410	1534	
Furnace 4; heat 62	1375										1387	1508	Clean.
Furnace 1; heat 32	1403	1403	1409	1393	1409	1407	1407	1399			1420	1546	
Furnace 1; heat 25	1410			1414	1410	1406	1401	1408	1412	1403	1407	1531	Spots.
Furnace 2; heat 10	1382	1377	1367								1401	1524	5000-pound skull.
Furnace 3; heat 73	1403	1397									1412	1537	
Furnace 3; heat 74													Spots.
Furnace 4; heat 51	1408	1406	1397								1413	1538	
Furnace 1; heat 36	1424	1406	1389	1389	1394						1414	1539	Clean.
Furnace 1; heat 41	1422	1410	1410								1414	1539	New ladle spots.
Furnace 3; heat 80	1408	1406	1397								1411	1536	Hot ladle spots.
Furnace 1; heat 42	1397	1392	1385	1380	1373						1414	1539	Spots.
Furnace 3; heat 82	1394	1403	1389								1402	1525	
Furnace 1; heat 43	1387	1385	1387	1383							1392	1514	
Mean	1401	1399	1395	1392	1396	1406	1404	1404	1412	1403	1406	1530	
Emissivity correction	123	123	122	122	122	124	124	124	125	124	1407		
True temperature	1524	1522	1517	1514	1518	1530	1528	1528	1537	1527		1531	

TABLE 4

Measurement of Open-Hearth Furnace Tapping and Ingot Teeming Temperatures

[Tapping and teeming temperatures are corrected for emissivity of iron, e=0.40; corrections for slag are less, e=0.65 usually for dark slag]

Tapping and teeming temperatures	Furnace No. 5; heat No. 55		Furnace No. 10; heat No. 08		Furnace No. 8; heat No. 30		Furnace No. 12; heat No. 46	
	Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature
Tapping temperatures..	9.47	1612	.....	.....	11.25	1623	2.46	1612
		1656	.....	.....	.....	1615	.....	1596
		a 1684	.....	.....	.....	b 1624	.....	.....
		a 1684	.....	.....	.....	b 1636	.....	.....
		a 1690	.....	.....	.....	1643	.....	.....
	c 9.50	*a 1704*	.....	.....	.....	1646	.....	.....
		.....	.....	.....	.....	(d)	.....	.....
		.....	.....	.....	11.29	(e)	.....	.....
Average f.....	.....	g 1634	.....	.....	.....	1632	.....	1604
Teeming temperatures: h								
First group.....	9.53	1579	.....	.....	11.35	1565	3.05	1550
		1588	.....	.....	5′ 10″	1562	.....	1545
		.....	.....	.....	.....	1567	.....	1540
Second group.....	.....	1636	.....	.....		1560	.....	1539
		1643	.....	.....	5′ 05″	1567	.....	1535
						1571	3.10	1534
Third group.....	.....	1606	5′ 45″	1567	.....	1576	3.15	1561
		1615	.....	1553	5′ 00″	1579	.....	i 1559
						j 1569	3.20	k 1540
Fourth group.....	.....	1588	5′ 35″	1545	.....	1568	3.23	l 1562
		1596	.....	1548	4′ 06″	1584	.....	l 1582
						1588	.....	m 1576
Fifth group.....	.....	1574	6′ 00″	k 1543	12′ 00″	n 1585	.....	.....
		1577	.....	j 1547	3′ 26″	1592	.....	.....
						o 1629	.....	.....
Sixth group.....	.....	.....	3′ 00″	1547	.....	.....	.....	.....
				1548	.....	.....	.....	.....
Average p.....	.....	1600	.....	1550	.....	1574	.....	1545

a Slag.

b Metal and slag.

c When e=0.65, t=1622.

d Slag. When e=0.65, t=1615.

e Slag. When e=0.65, t=1625.

f Average temperatures do not include observations shown in italics. The state of metal was good in each furnace. The color of slag was dark in furnace No. 5; yellow in furnaces No. 10, No. 12, and the two furnaces numbered 9; and creamy in furnace No. 8 and the two furnaces numbered 7.

g Too low (?).

h Size of nozzle in each instance was 3 inches, except for furnace No. 12, where it was 4 inches.

i Bad stream.

j Streaky stream.

k Good stream.

l Smoke and streaky stream.

m Changed position of pyrometer.

n Bad daylight effect.

o Slag (?). When e=0.65, t=1554.

p The heat of metal was hot and the behavior of metal in molds good in each case.

TABLE 4—Continued

Measurements of Open-Hearth Furnace Tapping and Ingot Teeming Temperature—Continued

Tapping and teeming temperatures	Furnace No. 7; heat No. 66		Furnace No. 9; heat No. 61		Furnace No. 7; heat No. 67		Furnace No. 9; heat No. 62	
	Time	Temperature	Time	Temperature	Time	Temperature	Time	Temperature
Tapping temperatures	3.45	1665	4.45	1634	.....	1583	10.52	1617
		1671	.....	1630	.....	1582	.....	1604
		[a] 1707	4.48	[b] 1691	.....	1579	.....	1577
						[c]		[d]
						[e]		
Average [f]	.....	1667	.....	1632	.....	1581	.....	1600
Teeming temperatures: [g]								
First group	3.53	1578	.....	1548	5′ 12″	1576	.....	1548
	5′ 50″	1581	.....	.....	.....	.....	.....	1541
		1580	.....	.....	.....	.....	.....	.....
Second group	.....	[h] 1598	.....	1555	.....	1555	.....	1535
	6′ 00″	1603	.....	1561	5′ 08″	1559	.....	1541
		[i] 1615	.....	.....	.....	1567	.....	.....
Third group	5′ 55″	1613	.....	1557	.....	1575	.....	1550
		1616	.....	1575	4′ 59″	1582	.....	1546
						1567	.....	.....
Fourth group	.....	1608	.....	1567	.....	1569	.....	1525
	4′ 40″	1607	.....	.....	4′ 06″	1573	.....	1531
		1605	.....	.....	.....	1572	.....	.....
Fifth group	.....	1598	.....	.....	.....	1555	.....	.....
	3′ 00″	1597	.....	.....	3′ 04″	1547	.....	.....
		1602	.....	.....	.....	1534	.....	.....
Sixth group	4.27	1610	.....	.....	.....	.....	.....	.....
Average [j]	.....	1601	.....	1561	.....	1564	.....	1540

[a] Slag (?). When e=0.65, t=1625.
[b] Slag (?). When e=0.65, t=1610.
[c] Slag. When e=0.65, t=1579.
[d] Slag. When e=0.65, t=1595.
[e] Slag. When e=0.65, t=1583.
[f] Average temperatures do not include observations shown in italics. The state of metal was good in each furnace. The color of slag was dark in furnace No. 5; yellow in furnaces No. 10, No. 12, and the two furnaces numbered 9; and creamy in furnace No. 8 and the two furnaces numbered 7.
[g] Size of nozzle in each instance was 3 inches, except for furnace No. 12, where it was 4 inches.
[h] Good stream.
[i] Bad stream.
[j] The heat of metal was hot and the behavior of metal in molds good in each case.

TABLE 5

Temperatures of Tapping Open-Hearth Furnaces

FURNACE NO. 12, HEAT NO. 36 [a]

Time in seconds	Observation temperature	True temperature	Stream of—	e	Time in seconds	Observation temperature	True temperature	Stream of—	e
25	1400	1520	Metal.	0.40	175	1435	1560	Metal.	0.40
50	1410	1535	...do...	.40	200	1435	1560	...do...	0.40
75	1425	1550	...do...	.40	225	1435	1560	...do...	0.40
100	1435	1560	...do...	.40	250	1435	1560	...do...	0.40
125	1445	1570	...do...	.40	275	1490	1550	Slag...	0.65
150	1440	1565	...do...	.40	300	1485	1545	...do...	0.65

[a] Twelve observations from smoky side; slag is ye llow in color.

TABLE 5—Continued

Temperature of Tapping Open-Hearth Furnaces—Continued

FURNACE NO. 7, HEAT NO. 14 [b]

Time in seconds	Observation temperature	True temperature	Stream of—	e	Time in seconds	Observation temperature	True temperature	Stream of—	e
12	1575	1710	Metal.	0.40	72	1505	1630	Metal.	0.40
24	1560	1690	...do...	.40	84	1495	1620	...do...	0.40
36	1535	1665	...do...	.40	96	1525	1630	Mixed.	?.50
48	1515	1640	...do...	.40	108	1565	1630	Slag...	.65
60	1510	1635	...do...	.40	120	1535	1600	...do...	.65

FURNACE NO. 8, HEAT NO. 79 [b]

10	1530	1675	Metal.	0.40	70	1515	1655	Metal.	0.40
20	1525	1670	...do...	.40	80	1525	1665	(?)	.40
30	1520	1665	...do...	.40	90	1545	1655	Mixed.	?.50
40	1515	1655	...do...	.40	100	1600	1670	Slag...	.65
50	1515	1655	...do...	.40	110	1600	1670	...do...	.65
60	1510	1650	...do...	.40	120	1585	1655	...do...	.65

FURNACE NO. 10, HEAT NO. 90 [c]

20	1480	1615	Metal.	0.40	140	1500	1635	Metal.	0.40
40	1480	1615	...do...	.40	160	1495	1630	...do...	.40
60	1480	1615	...do...	.40	180	1485	1620	...do...	.40
80	1485	1620	...do...	.40	200	1470	1605	...do...	.40
100	1490	1625	...do...	.40	220	1450	1585	...do...	.40
120	1500	1635	...do...	.40					

[b] Slag is creamy in color.

[c] Held 20 minutes with no fuel before casting. Slag is dark in color.

TABLE 6

Temperature of Stream During Tapping of Heat 12 × 36 [a]

Time	Pyrometer galvanometer reading	Apparent temperature	Correction for emissivity	True temperature	Remarks
3h 26m 00s	883	1424	127	1551	Metal stream started.
8	862	1375	119	1494	Smoky.
17	863	1378	119	1497	Do.
25	867	1387	121	1508	Do.
33	878	1413	125	1538	Smoke cleared.
42	875	1406	124	1500	e=0.40 for metal stream.
50	880	1418	126	1544	
57	883	1424	127	1551	
3 27 3	884	1427	127	1554	
10	884	1427	127	1554	
17	885	1429	127	1556	
23	891	1443	130	1573	
30	880	1418	126	1544	
36	883	1424	127	1551	
42	883	1424	127	1551	
49	885	1429	127	1556	
55	889	1438	129	1567	

[a] e=0.65 for slag stream.

TABLE 6—Continued

Temperature of Stream During Tapping of Heat 12 × 36—Continued

Time	Pyrometer galvanometer reading	Apparent temperature	Correction for emissivity	True temperature	Remarks
3h 28m 1s	880	1418	126	1544	
7	891	1443	130	1573	
14	893	1459	132	1591	
20	893	1447	130	1577	
26	893	1447	130	1577	
33	887	1433	128	1561	
40	889	1438	129	1567	
47	889	1438	129	1567	
54	891	1443	130	1573	
3 29 1	882	1422	127	1549	
8	880	1418	126	1544	
15	888	1436	129	1565	
21	881	1420	126	1546	
28	889	1438	129	1567	
34	892	1445	130	1575	
41	881	1420	126	1546	
47	887	1433	129	1562	
54	887	1433	129	1562	
3 30 00	895	1452	131	1583	
9	883	1424	127	1551	
18	888	1436	129	1565	
27	887	1433	129	1562	
37	883	1424	127	1551	
46	887	1433	129	1562	
55	881	1420	127	1547	
3 31 4	912	1491	62	1553	Slag stream.
13	912	1491	62	1553	Do.
22	908	1482	61	1543	Do.
31	883	1424	58	1482	Slag stream smoky.
40	870	1494	56	1450	Do.
50	898	1459	60	1519	Slag stream.
59	877	1410	57	1467	Slag stream smoky.
3 32 8	877	1410	57	1467	Do.
17	858	1366	54	1420	Do.

TABLE 7

Miscellaneous Metal Stream Temperatures

	Metal from cupola	Metal pouring from 1000-ton mixer	Metal pouring into 1000-ton mixer	Spiegel pouring into ladle	Recarbonizing iron pouring from small ladle	Blast-furnace iron going into open-hearth mixer
	1294	1275	1300	1195	1178	1254
	1287	1262	1295	.....	1178	.....
	1283	1270	1293	.....	1225	.....
	.....	1268	1268	.....	1192	.....
	.....	1244	1278	.....	.....	.....
	.....	1289	1303	.....	.....	.....
Average	1288	1268	1290	1195	1193	1254
Correction for emissivity, e=0.40	105	104	106	94	94	102
True temperature	1394	1372	1396	1289	1287	1356

TABLE 8

Open-Hearth Furnace Temperatures [a]

HEAT NO. 5X64

[Casting temperature, metal 1625, slag 1606; teeming temperature, 1540]

Time	Left door		Middle door		Right door		Direction of flames	Remarks
	Morse	Fery	Morse	Fery	Morse	Fery		
2.35 a. m.								Furnace charged.
11.05 a. m.	1635		1657		1633		R to L.	
11.20 a. m.							L to R.	Flame reversed.
11.22 a. m.			1635	1575				
11.28 a. m.			1716F	1650F	1629			
11.40 a. m.			1586					No flames.
11.41 a. m.	1607				1612		R to L.	
1.31 p. m.	1762F	1705F	1677	1680F	1635	1635F	L to R.	Reversed flames at 1.40.
2.00 p. m.								Charged feldspar.
2.39 p. m.	1642	1575 1690	1612	1575 1690	1590	1580 1690	L to R.	Reversed flames 2.39.
3.00 p. m.			1567					Reversed flames.
3.05 p. m.			1603				R to L.	After charging feldspar.
3.15 p. m.	1607		1605				do.	
3.19 p. m.						1573		Reversing flames.
3.32 p. m.	1747		1595			1622	L to R.	
3.36 p. m.			1588					Do.
3.39 p. m.			1622	1565			R to L.	
3.43 p. m.			1622					
3.48 p. m.			1761F	1640F				
4.27 p. m.	1635		1659		1673		R to L.	
4.34 p. m.			1691F	1615 1680F			do. do.	
4.36 p. m.			1635				L to R.	Do.
5.09 p. m.	1666		1688 1675 1653 1614		1631		R to L.	Cutting off flames. Reversing flames.
5.20 p. m.			1653				L to R.	Flames on.
5.30 p. m.								Furnace tapped.

HEAT NO. 3X97

[Casting temperature, metal 1597, slag 1612; teeming temperature, 1533]

1.47 p. m.	1636		1569		1636		R to L.	Metal not melted down.
3.10 p. m.	1588		1598		1614		do.	
3.56 p. m.	1607		1573		1620		do.	
3.58 p. m.					1571 1603		L to R.	Reversing.
4.47 p. m.	1657		1599		1627		do.	
5.56 p. m.	1693		1588		1586		do.	
7.16 p. m.	1709		1579		1567		do.	
7.35 p. m.	1733		1655		1620		do.	
7.40 p. m.								Furnace tapped.

[a] F opposite temperatures are for observations taken on flames; all other observations were taken with instruments sighting on the surface of the slag.

TABLE 8—Continued

Open-Hearth Furnace Temperatures—Continued

HEAT NO. 5×65

[Casting temperature, slag 1610; teeming temperature, 1520]

Time	Left door		Middle door		Right door		Direction of flames.	Remarks
	Morse	Fery	Morse	Fery	Morse	Fery		
9.25 a. m.	1686	.....	1659 1738F	.....	1666	.....	L to R.	
9.34 a. m.	1679	.....	1660	.....	1653	.....	...do.	
9.36 a. m.	.....	.....	.....	.....	.....	.....	.....	Furnace tapped.

HEAT NO. 3×98

[Casting temperature, metal 1559, slag 1621; teeming temperature, 1529]

9.30 a. m.	1765	.....	1664	.....	1679	.....	L to R.	
10.29 a. m.	1699	1530	.....	.....	.....	.....	R to L.	
10.32 a. m.	1709F	1530F	1772F	1595F	1704F	1565	L to R.	
10.40 a. m.	1677	1535	1700	1535	.....	.....	...do.	
11.00 a. m.	.....	.....	1702	.....	.....	.....	.....	
11.10 a. m.	.....	.....	.....	.....	.....	.....	.....	Furnace tapped.

HEAT NO. 4×62

[Casting temperature, metal 1628, slag 1659; teeming temperature, 1531]

11.48 a. m.	.....	.....	.....	.....	.....	.....	.....	Reversed.
11.49 a. m.	1573 1629F	....	1620 1688F	....	1657 1798F	....	R to L. ...do.	
11.58 a. m.	.....	1570F	.....	1615F	.....	1665F	...do.	
11.58 a. m.	.....	1520	.....	1535	.....	1545		
12.14 p. m.	.....	.....	.....	.....	.....	.....	.....	Do.
12.15 p. m.	1693	1530	1668	1570	1612	1530	L to R.	
12.20 p. m.	.....	1660F	.....	1625F	.....	1545F	...do.	
12.29 p. m.	.....	1645F	.....	1635F	.....	1575F	...do.	
1.53 p. m.	.....	1550F 1425	.....	1490F 1375	.....	1410F 1365	...do.	
1.59 p. m.	1668	.....	1646	.....	1599	.....	...do.	
2.01 p. m.	.....	.....	.....	.....	.....	.....	.....	Do.
2.15 p. m.	.....	.....	.....	.....	.....	.....	.....	Added cast iron.
2.20 p. m.	.....	1555F	.....	1580F	.....	1615F	R to L.	
2.48 p. m.	.....	1735F	.....	1670F	.....	1595F	L to R.	
3.03 p. m.	.....	1585	.....	1570	.....	1580	R to L.	
3.20 p. m.	1612 1655	.....	1612	.....	1603	.....	L to R.	Flames off.
3.24 p. m.	.....	1605	.....	1610	.....	1590	...do.	
3.41 p. m.	.....	.....	.....	.....	.....	.....	.....	Furnace tapped.

TABLE 9

Open-Hearth Furnace Temperatures

FURNACE NO. 10, HEAT NO. 90

[Casting temperature, 1635 to 1585]

Time	Oil from—	Ports		Spoon	Remarks
		Left	Right		
10.02 a. m.	L		1711		
10.56 a. m.	L		1701		
11.04 a. m.			1692		
11.10 a. m.				1640	At 11.11 charged ferromanganese.
11.12 a. m.	Off		1532		Clear. Oil cut off at 11.10.
11.14 a. m.	Off		1510		At 11.13 charged ferromanganese.
11.24 a. m.	Off		1378		
11.26 a. m.	Off			1545	
11.29 a. m.	Off			1522	
11.33a. m.	Off				Tapped furnace.

FURNACE NO. 8, HEAT NO. 79

[Casting temperature, 1675 to 1650 in two minutes]

9.41 a. m.	R	1657			Flames.
9.46 a. m.	L	1604			Clear.
9.47 a. m.				1604	
9.50 a. m.	L	1630			Flames.
9.56 a. m.	L		1640		Do.
10.42 a. m.	L	1630			
10.45 a. m.				1657	Charged ferromanganese.
10.47 a. m.	R	1655			
10.52 a. m.					Tapped furnace.

FURNACE NO. 7, HEAT NO. 14

[Casting temperature, 1710 to 1600 in two minutes]

10.07 a. m.	R	1653			
10.08 a. m.	L	1628			
10.10 a. m.				1598	
10.15 a. m.	L	1662			
10.20 a. m.				1612	
10.25 a. m.	R	1680			At 10.23 charged ferromanganese.
10.27 a. m.				1630	
10.36 a. m.					

TABLE 9—Continued

Open-Hearth Furnace Temperatures—Continued.

ACID FURNACE NO. 12; HEAT NO. 36

[Casting temperature 1520 to 1570 in six minutes. Stream viewed from smoky side]

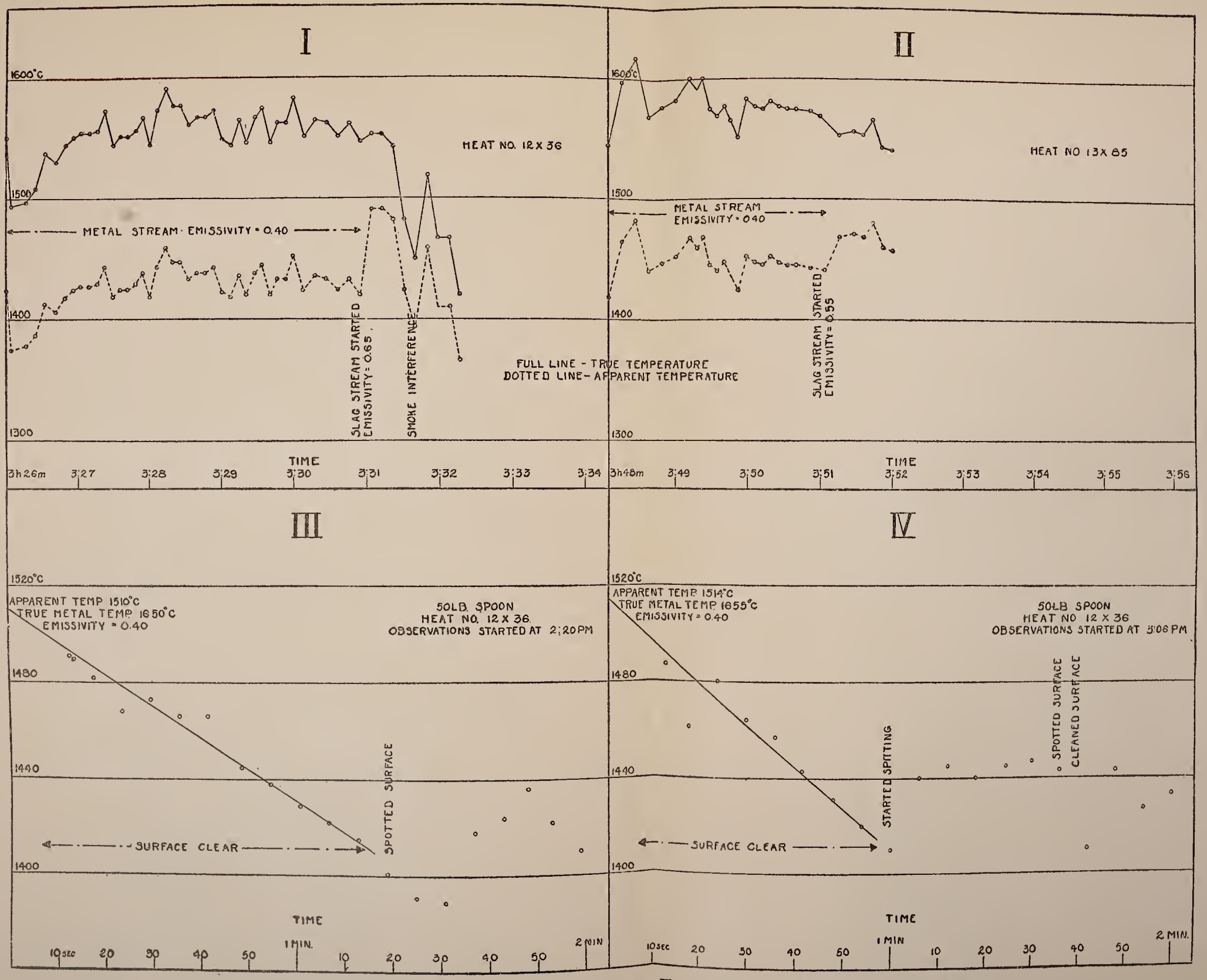
Time	Oil from—	Roof through ports		Bath slag	Spoon metal	Remarks
		Left	Right			
10.58 a. m.	R	1647	.....	.....	.....	Pyrometer sighted over flames; not melted yet.
11.02 a. m.	R	1666	.....	.....	.....	
11.04 a. m.	R	.....	1667	.....	.....	
11.09 a. m.	R	.....	.....	1623	.....	Bubbles appear dark.
11.17 a. m.	R	.....	.....	1602	.....	Slag bergs.
11.27 a. m.	R	.....	.....	1627	.....	
11.32 a. m.	R	1682	.....	.....	.....	Furnace stirred.
11.34 a. m.	R	.....	1667	.....	.....	Oil reversed to left.
11.39 a. m.	L	1694	.....	.....	.....	About melted.
11.43 a. m.	L	.....	1727	.....	.....	
11.48 a. m.	L	.....	1729	.....	.....	On flames.
11.51 a. m.	L	.....	.....	1655	.....	Black bubbles.
11.55 a. m.	L	.....	.....	.....	1566	At 12.01 reversed oil to right.
12.06 p. m.	R	1693	.....	.....	.....	Flames.
12.10 p. m.	.....	.....	1710	.....	.....	Not on brightest flames.
12.27 p. m.	R	.....	1694	.....	.....	O. K.; "medium furnace."
12.29 p. m.	.....	.....	.....	1653	.....	
12.33 p. m.	R	1687	.....	.....	.....	Uniform.
12.38 p. m.	L	.....	.....	.....	1584	At 12.34 reversed oil to left.
12.45 p. m.	L	.....	.....	.....	1618	
12.50 p. m.	L	.....	.....	.....	1604	
12.52 p. m.	L	.....	.....	1672	.....	Metal quiet; few bubbles.
12.53 p. m.	L	.....	1745	.....	.....	Fairly uniform.
12.55 p. m.	L	1725	.....	.....	.....	At 12.59 reversed oil.
1.16 p. m.	.....	.....	.....	.....	.....	Charging hematite.
1.21 p. m.	R	1710	.....	.....	.....	Fairly clear.
1.24 p. m.	R	.....	1710	.....	.....	
1.27 p. m.	R	.....	.....	1679	.....	At 1.31 reversed oil.
1.34 p. m.	L	.....	.....	.....	1649	At 1.42 reversed oil.
1.50 p. m.	R	.....	.....	.....	1660	
1.54 p. m.	R	1648	.....	.....	.....	Clear.
1.57 p. m.	R	.....	1640	.....	.....	Do.
2.00 p. m.	R	.....	.....	1638	.....	
2.14 p. m.	R	.....	1626	.....	.....	Do.
2.16 p. m.	R	.....	.....	1601	.....	Slag bergs.
2.17 p. m.	R	1633	.....	.....	.....	
2.20 p. m.	R	.....	.....	.....	1650	
2.28 p. m.	R	1628	.....	.....	.....	Clear.
2.29 p. m.	R	.....	.....	1606	.....	
2.31 p. m.	R	.....	1627	.....	.....	Do.
2.49 p. m.	R	1660	.....	.....	.....	
2.50 p. m.	.....	.....	.....	.....	.....	Charged ferrosilicon
2.51 p. m.	R	1655	.....	.....	.....	
2.54 p. m.	R	1650	.....	.....	.....	At 2.55 stirred furnace.
2.56 p. m.	R	.....	1674	.....	.....	Flames.
2.58 p. m.	.....	.....	.....	1638	.....	
3.01 p. m.	R	.....	.....	.....	1655	
3.06 p. m.	.....	.....	.....	.....	.....	Charged ferromanganese.
3.08 p. m.	R	1687	.....	.....	.....	
3.09 p. m.	R	.....	1702	.....	.....	Flames.
3.21 p. m.	.....	.....	.....	.....	.....	Hard tap lasted five minutes.
3.26 p. m.	.....	.....	.....	.....	.....	Tapped.
3.32 p. m.	.....	.....	.....	.....	.....	End of cast.

TABLE 10

Open-Hearth Bath Temperatures

[Pyrometer sighted on slag surface through middle door]

Time	Furnace No.—						Remarks
	8	9	10	11	12	13	
12.52 p. m.					1672		Metal quiet. Melted about 11.45.
12.58 p. m.						1623	Large bubbles.
1.05 p. m.				1677			Just grazing bath.
1.08 p. m.			1665				Large bubbles.
1.10 p. m.		1567					Melted at 12.30. Small bubbles.
1.13 p. m.	1660						About melted. Flames close to metal.
1.27 p. m.					1679		
2.29 p. m.					1606		
2.37 p. m.			1668				Bubbling hard.
2.38 p. m.		1642					Large slag bergs.
2.40 p. m.	1671						Melted at 1 p. m. Clear of slag bergs.
2.48 p. m.						1653	
2.58 p. m.					1638		
3.38 p. m.						1669	
3.41 p. m.				1634			O. K. Melted at 2.40 p. m.
3.44 p. m.			1649				
3.47 p. m.		1627					
3.50 p. m.	1623						Ready to tap.



I AND II · OPEN HEARTH TAPPING TEMPERATURES, III AND IV FURNACE TEMPERATURES BY SPOON METHOD.

81394°—17. (To follow page 29.)